Usp.fis.nauk, 60, fasc.2, 213-224 (1956) CARD 2 / 2 PA - 1697

The lectures delivered by various authors are separately discussed in short. An analysis of the principal results obtained leads to some conclusions concerning the main tendencies in the development of the modern theory of semiconductors. Apparently there are many such tendencies:
a) The electrons and oscillations of the lattice are considered to be a uniform system, in which case interaction between the conductivity electrons and phonons is not merely investigated, but the latter are included in the HAMILTONIAN of zero-th approximation, i.e. interaction is taken into account already on the occasion of the determination of the stationary states of the system. On this occasion a certain "conglomeration" of electrons and phonons serves as a current carrier.
b) The consistent many-electron method of solving a number of concrete problems: This method is of use only whenever the difference between the one-electron and the many-electron point of view makes itself felt, as for example in the theory of the electron plasm and in connection with some other problems of the modern theory of solids. A classical example herefore is the theory of the exiton. - c) The abandonment of a number of ideal methods for the development of the phenomenological theory. - d) Consideration of the concrete special properties of the energy spectrum on the occasion of the computation of kinetic coefficients.

INSTITUTION:

BONCH-BRUYEVICH, V.L., redaktor; GESSEN, L.V., redaktor; GERASIMOVA, Ye.S., tekhnicheskiy redaktor

[Problems in the physics of semiconductors; a collection of articles. Translated from the English] Problemy fiziki poluprovodnikov; sbornik statei. Perevod s angliiskogo. Pod red. V.L.Bonch-Bruevicha. Moskva, Izd-vo inostr. lit-ry, 1957. 629 p. (MLRA 10:10)
(Semiconductors)

AUTHOR: Bonch-Bruyevich, V.L. 126-3-26/34

TITLE: On the theory of electron plasma in the solid body. (K teorii elektronnoy plazmy v tverdom tele).

PERIODICAL: "Fizika Metallov i Metallovedeniye" (Physics of Metals and Metallurgy), 1957, Vol.4, No.3, pp.546-547 (U.S.S.R.)

ABSTRACT: The problem of plasma type oscillations in solid bodies has been the subject of numerous papers (1-5). This problem is important not only in itself but also in conjunction with the problem of screening the interaction between fermions themselves and between fermions and the external field. This is particularly clearly apparent in the formulation of the problem by the method of "excessive variables". However, it is necessary to take into consideration that in this method the "Bose-Fermi" relation is not unimportant. It is logically not quite satisfactory to introduce artificially the limit impulse Bose quantum hk_0. Limitation of the possible wavelength of the plasma oscillations should not be imposed but should be deduced from the theory itself. It is also pointed out that the authors referred to, i.e. Bohm, D. and Pines O. (1), Zubarev, D. N. (2), Klimantovich, Yu. L. (3), Tomonaga, S. (4), did not investigate the isotropic case. Apparently the

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On the theory of electron plasma in the solid body. (Cont.)

above mentioned complications can be avoided by applying the method of the Green function. It was shown in an earlier paper of this author (6) that the poles of the Green function (considered as functions of the frequency ω and of the wave vector $\vec{k}$) are directly inter-related with the frequencies of the respective excitations. Thus, the problem is reduced to investigating the features of the Bose-Green function for the system "Fermi-gas plus electromagnetic field" and naturally in the non-relativistic approximation only the longitudinal field is of interest. Eq.(17), p.547, expresses the spectrum of the plasma oscillations in the crystal with an arbitrary (non-degenerated) energy surface. Screening can easily be taken into consideration in this approximation but this problem will be the subject of a separate communication.

Card 2/2

There are 9 references, 5 of which are Slavic.

SUBMITTED: December 26, 1956.

ASSOCIATION: Moscow State University imeni M. V. Lomonosov. (Moskovskiy Gosudarstvennyy Universitet imeni M.V.Lomonosova)

AVAILABLE: Library of Congress

AUTHOR: BONCH-BRUYEVICH, V.L. PA - 2350

TITLE: On the Recombination of a Mechanism of Current Carriers in Highly Alloyed Semiconductors. (Ob odnom mekhanizme rekombinatsii nositeley toka v sil'no legirovannykh poluprovodnikakh, Russian).

PERIODICAL: Izvestiia Akad. Nauk SSSR, Ser. Fiz., 1957, Vol 21, Nr 1, pp 87 - 96 (U.S.S.R.).
Received: 4 / 1957 Reviewed: 5 / 1957

ABSTRACT: The present work investigates recombination with transfer of energy to oscillations of the type of plasma oscillations. The plasma oscillations of an electron-hole-gas in semiconductors: The many-electron-problem can be reduced to the more simple problem concerning the behavior of the system of elementary excitations ("surplus" electrons and holes). Taking account of interaction between them is a problem for itself. The authors generalize the method of the "collective variable" for the solution of the problem of interaction for the case with an exterior field and with two "kinds" of particles which are in interaction. It is then possible to write down the equation for the system of electrons and holes in coordinate representation in form of an ordinary Schrödinger equation. The Hamiltonian of this Schrödinger equation is given here. For the wave function an ansatz is given. In the representation of the second quantization the following wave equation is obtained: $H = H_1 + H_2 + H' + H'' + H'''$. The individual

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summands are explicitely given. The operators H_1 and H_2 describe the behavior of Fermi- and Bose excitations, which are not in interaction, in exterior fields they represent the main part of the Hamiltonian. The remaining summands in the above formula for H are considered as perturbation. The operator H' is of great importance when computing the energy spectrum of the system.

Next, the recombination of electrons and holes with transfer of energy to oscillations of the type of plasma oscillations is discussed. For reasons of concreteness a semiconductor of the electron type is investigated. The here investigated mechanism of the recombination of current carriers applies not only in the case of germanium (or silicon). Similar processes are e.g. possible also in compounds of the InSb type. (No illustrations or tables)

ASSOCIATION: Moscow State University, IMENI M. V. LOMONOSOVA
PRESENTED BY:
SUBMITTED:
AVAILABLE: Library of Congress.

Card 2/2

SUBJECT: USSR/Physics of Magnetic Phenomena 48-6-5/23

AUTHOR: Bonch-Bruyevich, V.L.

TITLE: On a Theory of Ferromagnetism in a Non-Ideal Lattice (K teorii ferromagnetizma v neideal'noy reshetke)

PERIODICAL: Izvestiya Akademii Nauk SSSR, Seriya Fizicheskaya, 1957, Vol. 21, # 6, p 801 (USSR)

ABSTRACT: A ferromagnetic substance with structural microdefects in its lattice has been analyzed within the framework of the exchange model. The structural microdefects can be unoccupied nodes, ions statically displaced from equilibrium positions, impurity atoms, etc.

Under certain conditions the presence of structural defects leads to the formation of local spin levels; these defects play the role of "demagnetization centers".

Results to which the application of these concepts lead in the theories of ferrites, of solid solutions of non-ferromagnetic substances in ferromagnetics and of ferromagnetics of small sizes, are laid down in the report published in

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48-6-5/23

TITLE: On a Theory of Ferromagnetism in a Non-Ideal Lattice (K teorii ferromagnetizma v neideal'noy reshetke)

detail in ФММ (FMM), Vol. 2, 1956, p 215.

No references are cited.

ASSOCIATION: Moskva State University im. Lomonosov

PRESENTED BY:

SUBMITTED: No date indicated

AVAILABLE: At the Library of Congress

Card 2/2

56-5-19/55

AUTHOR BONCH-BRUYEVICH, V.L.

TITLE Remarks on the Theory of the Electron Plasma in Semiconductors. (Zamechaniya k teorii elektronnoy plazmy v poluprovodnikakh-Russian)

PERIODICAL Zhurnal Eksperim.i Teoret.Fiziki, 1957, Vol 32, Nr 5, pp 1092-1097 (USSR)

ABSTRACT The paper under review investigates, on basis of the plural electron theory of the semiconductors, the scattering of cufrent carriers by a charged admixture, and also computes the ionization energy of the admixture centressof the third and the fifth group in the semi-conductors of the type of germaniu.
Estimate of the boundary value k_0 of the wave number: The author of the paper under review deals with semiconductors with current carriers of one type (for the sake of simplicity, they are called electrons.) Thus in the case under consideration the plasma is formed by electrons (or holes), which are supplied by the alloying admixture and by the positively (negatively) charged ions of the admixture. In this context, the concentration n of the electrons is constant and equals the concentration of the admixture. In general, however, there is no necessity of this quantity being identical with the concentration of the free current carriers. The author describes in his paper the fermions with the aid of the method of the effective mass. Under rigorous circumstances, the free energy of the entire system should have to minimized for the determination of k_0. However, the author limits himself here to an estimate of the extremely attainable values of K_0. The scattering by a charged admixture under considera-

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tion of the screening by a plasma: The screening factor in the potential energy has the following effects: (A) the elimination of the logarithmical divergence of the reciprocal relaxation time, which is characteristic of the purely Coulomb's scattering; (B) a considerable modification of the character of the scattering, if the mean thermal impulse p of the electron is smaller than or of the same order of magnitude as hk_0. At helium temperatures substantial deviations from the usual formula by Conwell and Weisskopf have to be expected. In order to illustrate these thoughts, the paper under review also investigates the scattering by a screening potential. At $p < \hbar k_0/2$ there exists no scattering at all. The last chapter of the presentpaper determihes the local levels under consideration of the screening by the plasma. Already at concentrations of the current carriers amounting to about 10^{15} to 10^{16} cm^{-3} the "plasmatic effects" become noticeable. At even higher concentrations (and also) at low temperatures these effects must be taken into account under any circumstances. (No reproductions).

ASSOCIATION Moscow State University.
PRESENTED BY
SUBMITTED 12.5.1956
AVAILABLE Library of Congress.
Card 2/2

AUTHOR: BONCH-BRUYEVICH, V.L. 56-6-26/56

TITLE: On the Exiton Mechanism of Capture of Current Carriers in Homopolar Semiconductors. (Ob eksitonnom mekhanizme zakhvata nositeley toka v gomeopolyarnykh poluprovodnikakh, Russian)

PERIODICAL: Zhurnal Eksperim. i Teoret.Fiziki, 1957, Vol 32, Nr 6, pp 1470-1478 (U.S.S.R.)

ABSTRACT: Theoretically the capturing process of a current carrier by structural defects is dealt with, on which occasion the transfer of energy is effected by an exiton with small radius. Furthermore, the temperature dependence of the recombination coefficient is determined, which, together with the concentration dependence, are to be experimentally determined in future. (With 8 Slavic References).

ASSOCIATION: Moscow University

PRESENTED BY:

SUBMITTED: 2.10.1956

AVAILABLE: Library of Congress

Card 1/1

56-7-41/66

AUTHOR BLANK, V.Z. (Deceased)
BONCH-BRUYEVICH, V.L., SHIRKOV, D.V.

TITLE A Note Concerning the Group of the Multiplicative Renormalization in the Quantum Theory of the Field. (Zamechaniye k gruppe mul'tiplikativnoy renormirovki v kvantovoy teorii polya.- Russian)

PERIODICAL Zhurnal Eksperim. i Teoret. Fiziki 1957, Vol 33, Nr 7, pp 265-266 (USSR)

ABSTRACT The renormalization group is not necessarily connected with the existence of divergences and occurs also in the "finite" theories, e.g. in the theory of the electron-photon-field in a solid body. The authors here investigate such a quantum theory of the field in which the LAGRANGIAN of the interaction (in interaction representation) takes the form

$$L(x) = \{g\bar{\psi}(x)\Gamma_0\psi(x) + J(x)\} A(x)$$

Here g denotes the coupling constant $\bar{\psi}, \psi$ and A - FERMI - and BOSE operators, Γ_0 - the elementary vertex part $x = \{\vec{x}, x_0\}$, J - the "outer current". Nothing definite is assumed here as to the tensorial character of Γ_0, J, A.

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A Note Concerning the Group of the Multiplicative Renormalization in the Quantum Theory of the Field.

Only A can also contain derivations according to the co-ordinates. Relations are given here for the packets of the free waves, for the total GREEN'S functions and for the vertex part.
The equations $G = G_o + ig^2 G_o \Gamma_o G \Gamma DG + gG_o G \Gamma_o a$,

$D = D_o - ig^2 D_o \Gamma_o G \Gamma GD$ are applicable to GREEN'S functions.

These two equations are invariant with respect to the following multiplicative representations of the orders of magnitude contained therein:

$$G \to z_2 G, D \to z_3 D, \Gamma \to z_1^{-1} \Gamma, g \to z_2^{-1} z_3^{-1/2} z_1 g.$$

Here z_1, z_2 and z_3 denote steady finite parameters. Not only the total functions G,D and Γ are transformed, but also the elementary functions G_o, D_o and Γ. The last mentioned four relations define in a general form the re-normalization group in the quantum theory of the field with a LAGRANGIAN of interaction of the form given above.

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If, in theory, also additional conditions occur (as e.g.

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A Note Concerning the Group of the Multiplicative Renormalization in the Quantum Theory of the Field.

the gradient invariance in quantum electrodynamics), then some of the constants occurring in the above mentioned four relations can be in connection with each other. The renormalization group, in fact, expresses a peculiar "automodel-like" behavior of SCHWINGER'S equations. Analogous contemplations can be carried out also in theories with other interaction LAGRANGIANS.
(No Illustrations)

ASSOCIATION: Moscow State University.
(Moskovskiy gosudarstvennyy universitet.- Russian)
PRESENTED BY: -
SUBMITTED: 11.1. 1957
AVAILABLE: Library of Congress.

CARD 3/3

BONCH-BRUYEVICH, V. L.: Doc Phys-Math Sci (diss) -- "Investigation of the multielectron theory of semiconductors". Moscow, 1958. 7 pp (Moscow Order of Lenin and Order of Labor Red Banner State U im M. V. Lomonosov), 150 copies

(KL, No 5, 1959, 142)

5(4)

AUTHORS: Bonch-Bruyevich, V.L., and Glasko, V.B. SOV/55-58-5-15/34

TITLE: On the Theory of Chemical Adsorption on Metals (K teorii khimicheskoy adsorbtsii na metallakh)

PERIODICAL: Vestnik Moskovskogo universiteta, Seriya matematiki, mekhaniki, astronomii, fiziki, khimii, 1958, Nr 5, pp 91 - 104 (USSR)

ABSTRACT: In § 1 the following questions are asked : a.) What kind of variations in the energetic spectrum of a system are connected with the process of chemical adsorption ? b.) What kind of effects arise by the possible appearance of a surface charge ? The authors try to give a qualitative answer on these questions. § 2 contains the foundations of the investigation essentially published by Bonch-Bruyevich [Ref 7 - 10] . § 3 Deals with the investigation of the influence of the structure defects on the electronic spectrum of the metal. All metals are divided into two classes with respect to the given adsorbate (and equally all the atoms of the adsorbate with respect to the given metal). In one of them the adsorption is accompanied by the formation of local levels, so that the metal does not differ from a semiconductor in this sense. In the second class there takes place no

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On the Theory of Chemical Adsorption on Metals SOV/55-58-5-15/34

formation of levels, the chemically adsorbed material is on the surface in the form of relatively weakly bound ions. § 4 Contains the approximative data, obtained by means of the computing machine Strela, on the local levels of atoms similar to hydrogen which are in the metal. The qualitative results of § 3 are confirmed. The authors thank F.F. Vol'kenshteyn, S.Z. Roginskiy and A.N. Tikhonov for the interest in the present paper.

There are 18 references, 12 of which are Soviet, 3 American, 2 German, and 1 English.

ASSOCIATION: Kafedra poluprovodnikov i kafedra matematiki dlya fizicheskogo fakul'teta (Chair of Semiconductors and Chair of Mathematics of the Physics Department)

SUBMITTED: June 24, 1958

Card 2/2

SOV/126-6-4-3/34

AUTHOR: Bonch-Bruyevich, V.L.

TITLE: On the Application of the Green's Function Method to the Multi-Electron Problem in a Solid Body (O primenenii metoda funktsiy Grina k mnogoelektronnoy zadache v tverdom tele)

PERIODICAL: Fizika metallov i metallovedeniye, 1958, Vol 6, Nr 4, pp 590-600 (USSR)

ABSTRACT: The main difficulty of the theory of metals is the problem of taking into account Coulomb interactions between electrons. It has been shown (Ref.1) that in a number of kinetic problems this difficulty may be circumvented by simply postulating the existence of a certain spectrum of elementary excitations. However, there are problems in which a dynamic treatment of a multi-electron system apparently cannot be avoided. Among these problems is the problem of the effect of various types of structural defects upon the electron energy spectrum, e.g. the theory of chemical absorption on metals. A dynamic treatment is also necessary for the case of plasma oscillations. Several attempts have been made in order to resolve this difficulty in

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On the Application of the Green's Function Method to the Multi-Electron Problem in a Solid Body

recent years (Ref.2-5). However, all these attempts involve various difficulties, many of which can be avoided by the use of Green's functions. Accordingly, the present paper is concerned with an electron gas with Coulomb interactions. The anisotropy of isoenergetic surfaces is taken into account and explicit expressions are obtained for the spectrum of plasma oscillations (Eq.4.11 which is analogous to the formula given by Wolf in Ref.16) and for the screening of the external field (Eq. 5.13). In connection with Eq.(4.11) it is pointed out that plasma oscillations cannot occur for any arbitrary form of the isoenergetic surfaces. This is clear from an inspection of the quadratic forms in Eq.(4.11). The case where $\mu_{ij} = 0$ and the tensors γ and σ are different from zero is possible in principle. In this case plasma oscillations are not different from ordinary sound.

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SOV/126-5-4-3/34

On the Application of the Green's Function Method to the Multi-Electron Problem in a Solid Body

The author considers that the statement that electrons in fully filled zones do not take part in plasma oscillations (Ref.16) is not correct. There are 16 references of which 12 are Soviet and the rest English.

ASSOCIATION: Moskovskiy Gosudarstvennyy Universitet Imeni M.V.Lomonosova (Moscow State University imeni M.V.Lomonosov)

SUBMITTED: 18th February 1957.

Card 3/3

SOV/126-6-5-1/43

AUTHOR: Bonch-Bruyevich, V.L.

TITLE: On the Application of a Renormalisation Group to the Coulomb Problem in a Solid (O primenenii gruppy perenormirovki k kulonovskoy zadache v tverdom tele)

PERIODICAL: Fizika Metallov i Metallovedeniye, 1958, Vol 6, Nr 5, pp 769 - 775 (USSR)

ABSTRACT: This paper continues the author's earlier work (Ref 1) on a system of electrons interacting according to Coulomb's law in a solid. He showed (Ref 1) that the problem of screening of electron interactions with lattice defects reduces to solution of the equation:

$$\left\{ \lambda - W(-i\nabla) + g \int d\vec{k} e^{i\vec{k}\vec{x}} \frac{e_{\text{эфф}}(\vec{\varkappa})}{\varkappa^2} \right\} \chi(\vec{x}) - \int d\vec{x}' M(\vec{x} - \vec{x}') \chi(\vec{x}') = 0 \qquad (1.1)$$

(the meaning of the various symbols is given in Ref 1).

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SOV/126-6-5-1/43

On the Application of a Renormalisation Group to the Coulomb Problem in a Solid

In subsequent calculations, it was found necessary to expand the mass and polarisation operators of Eq (1.1) in increasing powers of the coupling constant g^2. This constant was assumed to be small (much smaller than unity) which is true for some conductors but not for metals. The present paper shows how one can use the renormalisation group technique (Ref 2) to avoid this difficulty. The expansion in powers of g^2 is replaced by an expansion in increasing powers of an "invariant charge", which is a function of g^2 and the boson Green's function D. In the "invariant charge" expansion, g^2 need not be small any longer. The paper is entirely theoretical. There are 6 Soviet references.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet (Moscow State University)

SUBMITTED: April 11, 1957

Card 2/2

BONCH-BRUYEVICH, V.L.

57-1-10/30

AUTHOR: Bonch-Bruyevich, V. L.

TITLE: On the Distinction Between the Recombination Centers and the Trapping Levels (K voprosu o razlichii mezhdu tsentrami rekombinatsii i urovnyami prilipaniya).

PERIODICAL: Zhurnal Tekhnicheskoy Fiziki, 1958, Vol. 28, Nr 1, pp. 67-69 (USSR)

ABSTRACT: The most interesting case of holes in the n-material is investigated here. The probabilities are calculated per time unit and per one trap covered by the hole. The author shows that if a temperature dependence of the recombination coefficient is lacking the probability of the "recombination" effect in the case of temperature drop would increase. But in reality there is such a dependence (ref. 5) and it plays a main part in the case investigated here. The author shows that the transition from the recombination center to the adhesion level must take place here at $T \simeq 134^{\circ}K$ which does not contradict to the data of ref.3. The possible reasons for the important part of the temperature dependence of the recombination coefficient are investigated. It can be connected either with the presence of a potential barrier or with the characteristics of the drainage of the energy leaving with the trapping of the carriers. The author shows that the separation into recombination centers and adhesion levels has in no case

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absolute character. It is not only determined by the characteristics of the present concrete addition but also by the temperature the conditions under which the sample had been produced as well as by the conditions under which the injection had been carried out. The adhesion level is not characterized by a great but by a sufficiently small trapping cross section. From the formulae given here we see that the adhesion levels must most probably always be situated in the near of the center of the exclusion -zone. The work is discussed with S. G. Kalashnikov. There are 11 references 7 of which are Slavic.

ASSOCIATION: **Moscow State University,** Faculty for Physics (Moskovskiy gosudarstvennyy universitet, Fizicheskiy fakul'tet).

SUBMITTED: May 31, 1957

AVAILABLE: Library of Congress

BONCH-BRUYEVICH, V.L.

57-1-11/30

AUTHOR: Bonch-Bruyevich, V. L.

TITLE: On the Theory of the Field Effect (K teorii effekta polya).

PERIODICAL: Zhurnal Tekhnicheskoy Fiziki, 1958, Vol. 26, Nr 1, pp. 70-76 (USSR)

ABSTRACT: Here the influence of the alternating transversal field on the conductivity of the semiconductor with random ratio between the Debye- length L_d and the free way length 1 is investigated. As the diffusion length exceeds noticeably the measurements of the sample the volume recombination is neglected and only the surface recombination is taken into account. In dependence on the characteristics of the sample there are here 2 principally different possibilities. If $L_t \ll 1 (\sim 10^{-5}$ cm), the charge in the traps can practically be regarded as a surface charge (in the sense of electrostatics) and it can be taken into account only with the boundary conditions of the Poisson equation. Lt is the thickness of the layer covered by surface traps. The recombination coefficients are contained in this problem only by means of the equation which expresses the current-carrier exchange between the traps and zones. On the other hand, if $L_t \sim 1$, the continuity--equation must be put down in order to take into account the recombination. In this case the recombination is a volume recombination. Here the first possibility is investigated as it is that

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possibility which is apparantly closer to reality. The author shows that as soon as the surface traps are concentrated in a sufficiently thin layer ($L_t \ll 1$) the general character of the frequency dependence of the field effect depends little on the ratio of the free way lengths and the screening. Here the frequency-dependence of the effect is expressed by a simple formula similar to that in ref. 1. If the thickness of the surface layer, which is covered by the recombination centers, is comparable to 1 ($L_t \sim 1$) the said dependence can become very complicated. Then the surplus concentration becomes dependent on the frequency and therefore the spectrum of the field effect becomes much more complicated. The work was discussed with S. G. Kalashnikov and A. E. Yunovich. There are 5 references, 1 of which is Slavic.

ASSOCIATION: **Moscow State University,** Faculty for Physics (Moskovskiy gosudarstvennyy universitet, Fizicheskiy fakul'tet).

SUBMITTED: June 7, 1957

AVAILABLE: Library of Congress

APPROVED FOR RELEASE: 06/09/2000 CIA-RDP86-00513R000206210010-9"

56-1-55/56

AUTHORS: Bonch-Bruyevich, V. L. , Gertsenshteyn, M. Ye.

TITLE: On the Theory of the Magnetic Susceptibility of Metals (K teorii magnitnoy vospriimchivosti metallov)

PERIODICAL: Zhurnal Eksperimental'noy i Teoreticheskoy Fiziki, 1958, Vol. 34, Nr 1, pp. 261 - 261 (USSR)

ABSTRACT: The magnetic susceptibility of the electron gas was recently (references 1, 2, 3) calculated with the taking into account of the distant Coulomb correlation. In this connection, however, only the susceptibility caused by the Fermi branch of the spectrum of excitations was taken into account. But the authors want to call attention to the fact that the Bose quanta of plasma vibrations also furnish a certain contribution to the susceptibility. It is true that these excitations are neutral and do not furnish any contribution to the current, but their energy depends on the field strength of the magnetic field H and therefore the plasma-quanta are"carriers of magnetism". At the usual temperatures the real plasma-quanta are practically not excited in metal, but their zero energy also depends on H. This leads, as shown here, to a plasma--diamagnetism comparable with the Landau diamagnetism. In a weak magnetic field a separation of the plasma vibrations in longitu-

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56-1-55/56

On the Theory of the Magnetic Susceptibility of Metals

dinal and transversal vibrations is also possible. For the case discussed here only the former are of interest. An expression for the frequency of the longitudinal plasma-quantum is given. Then the author gives an expression for the magnetic susceptibility caused by the dependence of the zero energy of the plasma on the magnetic field. The neglect of the zero energy of the plasma is generally not at all justified and the quantitative agreement of the theory by Pines (reference 1) with the experiment must anew be checked. There are 5 references, 2 of which are Slavic.

ASSOCIATION: Moscow State University (Moskovskiy gosudarstvennyy universitet)

SUBMITTED: November 21, 1957

AVAILABLE: Library of Congress

Card 2/2

AUTHOR: Bonch-Bruyevich, V. 53-64-4-11/11

TITLE: Bibliography (Bibliografiya)

PERIODICAL: Uspekhi Fizicheskikh Nauk, 1958, Vol. 64, Nr 4, pp. 797 - 798 (USSR)

ABSTRACT: The author discusses in detail the book by Ch. Kittel' "Introduction to the Physics of Solids" (Vvedeniye v fiziku tverdogo tela) published by the Gcstekhizdat publishers in 1957. The introduction to this book is by A. A. Gusev.

Card 1/1

BONCH-BRUYEVICH, V.L., red.; GESSEN, L.V., red.; GRIBOVA, M.P., tekhn.red.

[Recombination of carriers in semiconductors; collection of articles] Rekombinatsiia nositelei toka v poluprovodnikakh; sbornik statei. Moskva, Izd-vo inostr.lit-ry, 1959. 140 p. (MIRA 13:1)

(Semiconductors)

BONCH-BRUYEVICH, V.L., red.; MAYKOVA, Ye.I., red.; ZOTOVA, N.V., tekhn.red.

[Quantum theory of many bodies; articles translated from the English] Voprosy kvantovoi teorii mnogikh tel; sbornik statei. Pod red. V.L.Bonch-Bruevicha. Moskva, Izd-vo inostr. lit-ry, 1959. 266 p. (MIRA 13:6)
(Problem of many bodies)

BONCH-BRUYEVICH, V.L.

Spin mechanism for a current carrier recombination in ferromagnetic semiconductors. Fiz. tver. tela 1 no.2:186-191 F '59. (MIRA 12:5)

1. Moskovskiy gosudarstvennyy universitet im. M.V. Lomonosova.
(Semiconductors) (Quantum theory)

66254
SOV/181-1-7-10/21

~~24(6)~~ 24.7700

AUTHOR: Bonch-Bruyevich, V. L.

TITLE: Refined Theory of Plasma Recombination

PERIODICAL: Fizika tverdogo tela, 1959, Vol 1, Nr 7, pp 1076-1083 (USSR)

ABSTRACT: Investigation of the recombination of current carriers is one of the most important problems of modern semiconductor physics. The process concerned here is the transition of current carriers from the conduction band to a local level under the emission of a plasma quantum. The author investigated the probability of such a transition on the basis of the interaction Lagrangian (1), and equation (2) is given for an S-matrix element that defines the capture of a current carrier. Herefrom the probability of capture of a carrier is calculated in equation (5), and equation (10) yields the recombination coefficient of nondegenerate media. Two cases were investigated in calculating the matrix element according to equation (6): (1) The extrinsic donor and acceptor levels in germanium and silicon offer an approximate definition within the framework of the hydrogen model. (2) A deep trap. Consideration of the results shows that the recombination coefficient for the case of a deep trap does not greatly depend on the temperature and concentration of the majority carriers. 4

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Formulas (25) and (26) define the capture of majority and minority carriers. The absolute value of capture cross section is not so easy to determine, whereas that of the recombination coefficient of hydrogen-like traps can be calculated much more exactly. An appendix deals with the limit wave number of plasma oscillations, and an equation is given here for the wavelengths of the plasma quanta. Calculations were made by V. A. Druzhinina and V. I. Zhevoruyeva at the Computer Bureau, Kafedra matematiki fizicheskogo fakul'teta MGU (Chair of Mathematics of the Department of Physics of Moscow State University) under the supervision of V. B. Glasko, for which the author expresses his gratitude. There are 1 figure and 12 references, 10 of which are Soviet.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet, Fizicheskiy fakul'tet (Moscow State University, Department of Physics) 4

PRESENTED: April 2, 1958

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67305

SOV/181-1-8-10/32

AUTHOR: Bonch-Bruyevich, V. L.

TITLE: On the Theory of Impurity Bands

PERIODICAL: Fizika tverdogo tela, 1959, Vol 1, Nr 8, pp 1213 - 1220 (USSR)

ABSTRACT: The author investigates a donor system of the type of the 5th group in germanium. For the approximations in the present paper only a few formulations have to be changed when passing over to the case of an acceptor. Donor concentration N is assumed to be sufficiently low in order to be able to neglect a direct superposition of the discreet-spectrum wave functions belonging to different impurity atoms. The author employed the effective mass method in its isotropic variation. States of isolated donors in the scope of the hydrogen model are described only in consideration of potential screening. The estimation of the impurity band width found here is probably somewhat too low (but certainly not for a whole order of magnitude). However, this is insignificant as long as one desires only a proof for the existence of this impurity band. In the second paragraph the required calculations are described step by step. The energy shifts of the ground level caused by inter-

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On the Theory of Impurity Bands

action of one electron with all other donors are investigated in second approximation of the perturbation theory. After rather lengthy calculations $\Delta W \sim 3.10^2 \frac{\sqrt{d+a}}{d^3}$ is found for the width of the impurity band, a denoting the scattering length, and $d \sim N^{-1/3}$ the distance between two adjacent donors. $\Delta W \sim N^{5/6}$ holds because the scattering length is either small as compared to d, or is of the same order as d. Thus, for low impurity concentrations the impurity band width increases about proportionally to the concentration. An impurity band width estimation in germanium with αd = 100 (which corresponds to the case $N \sim 2.10^{14}$ cm^{-3}) results in $\Delta W \gtrsim 6.10^{-5}$.ev. The approximation of the nearest neighbors which leads to the well-known cosine law does not apply here, and the experiments on the impurity band may be interpreted according to this law only with reservation. Thus, the phenomena connected with the existence of an impurity band may hardly be described by the usual theory of kinetic coefficients in semiconductors. This holds even for the most simple case, i.e., for electric 4

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SOV/181-1-8-10/32

On the Theory of Impurity Bands

conductivity in semiconductors. The problem of galvanomagnetic phenomena becomes particularly complicated. Electron energy quantization in a magnetic field gives absolutely unusual results: the Landau levels must "run" in a band of a width comparable to ΔW. An impurity band is observable even with low impurity concentrations, not only in the theory of kinetic coefficients at low temperatures but also in the interpretation of some other phenomena occurring in semiconductors. The author thanks L. E. Gurevich, M. I. Klinger, and A. G. Samoylovich for interesting discussions. There are 18 references, 8 of which are Soviet.

ASSOCIATION: Institut radiotekhniki i elektroniki AN SSSR, Moskva (Institute of Radio Engineering and Electronics of the AS USSR, Moscow)

SUBMITTED: July 4, 1958

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67306

9.3150

~~9 (3)~~

AUTHORS: Bonch-Bruyevich, V. L., Kogan, Sh. M. SOV/181- 1 -8-11/32

TITLE: On the Theory of the Electron Plasma in Semiconductors

PERIODICAL: Fizika tverdogo tela, 1959, Vol 1, Nr 8, pp 1221 - 1224 (USSR)

ABSTRACT: First, previous papers are briefly mentioned. Although the ansatz of the Schwinger equation offers no principal difficulties, its practical setup is more difficult than in the general case since in general interaction energy has to be considered not only in quantum averaging but also in statistical averaging. Therefore, the present paper is confined to an approximate problem. The vertex operator, the mass operator, and the polarization operator are expanded in series according to the coupling constant, however, in consideration of only the first non-vanishing terms. Knowledge of the "free" Green function $G^{(o)}_{ss'}(x,y) = i\langle T\{\psi_s(x)\bar{\psi}_{s'}(y)\}\rangle$ given by Fermi is sufficient for calculating D. The symbol $\langle\ldots\rangle$ means averaging over the canonical assembly in the nondisturbed system; ψ and $\bar{\psi}$ denote the Fermi operators; x, y the points in four-dimensional space; s, s' the spin indices. For simplicity, the above formula is explicitly written down only for non-degenerate zones. An

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On the Theory of the Electron Plasma in Semiconductors SOV/181-1-8-11/32

expression for the plasma frequencies is derived and specialized for square approximation. In the perfectly degenerate case this term assumes the form of a result given by the authors in two previous papers. In the following the authors deal with the law of screening; they investigate the field of a static point charge and, for simplicity, confine their studies to the isotropic model. An expression for the corresponding screened potential is written down and re-written for the non-degenerate and the perfectly degenerate case. Even in a non-degenerate gas Debye's law holds only asymptotically, i.e., at large distances from the charge center. In such investigations the problem of the parameter of expansion can be solved only by means of the renormalization group. There are 16 references, 9 of which are Soviet.

ASSOCIATION: Institut radiotekhniki i elektroniki AN SSSR, Moskva (Institute of Radio Engineering and Electronics of the AS USSR, Moscow)

SUBMITTED: August 5, 1958

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24(5)
AUTHOR: Bonch-Bruyevich, V. L. SOV/126-7-2-3/39

TITLE: The Green's Function Method in Systems with Short-Range Forces (Metod funktsii Grina dlya sistem s korotkodeystvuyushchimi silami)

PERIODICAL: Fizika Metallov i Metallovedeniye, 1959, Vol 7, Nr 2, pp 174-180 (USSR)

ABSTRACT: The Green's quantum function method is used to discuss the ground state energies, correlation functions and fundamental excitation spectra of fermion and boson systems with short-range forces. The case of bosons is dealt with in detail. It is shown that the fundamental excitation spectrum obtained by Bogolyubov (Refs 6,7) for small momenta is valid for all interaction intensities. A new branch of the boson spectrum is found; it has a finite "gap". The paper is entirely theoretical. There are 8 references, 6 of which are Soviet and 2 English.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet imeni M. V. Lomonosova (Moscow State University imeni M. V. Lomonosov)

Card 1/2

SOV/126-7-2-3/39

The Green's Function Method in Systems with Short-Range Forces

SUBMITTED: February 19, 1958

Card 2/2

AUTHOR: Bonch-Bruyevich, V. L. SOV/126-7-3-26/44

TITLE: Plasma Oscillations in the Presence of Degenerate Bands (Plazmennyye kolebaniya pri nalichii vyrozhdennykh zon)

PERIODICAL: Fizika metallov i metallovedeniye, 1959, Vol 7, Nr 3, pp 448-450 (USSR)

ABSTRACT: In Refs 1 and 2 the Green function method was used to discuss plasma oscillations and the screening by free charges in a solid body. The isoenergetic surfaces in the unperturbed problem could have any form, subject only to the condition that the bands are nondegenerate. In the present paper the method given in Refs 1 and 2 is generalized to the case of degenerate bands. An expression is derived for the plasma resonance frequency (Eqs 11 and 12). The analysis is used to calculate m^* and ω_o for Ge and Si (Eqs 14 and 15). Fermion effective masses depend on their concentration and the isoenergetic surfaces which determine ω_o coincide with the experimentally observed surfaces for fermions, only for small n. There are 6 references, 4 of which are Soviet and 2 English.

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SUBMITTED: February 19, 1958

SOV/126-8-2-22/26

AUTHOR: Bonch-Bruyevich, V.L.

TITLE: On Ferromagnetics with Two Curie Points

PERIODICAL: Fizika metallov i metallovedeniye, 1959, Vol 8, Nr 2, pp 309 - 310 (USSR)

ABSTRACT: It was shown in the work of the author (Ref 1) that structural defects of a certain type can play the role of "demagnetization centres" in ferromagnetics. Near such defects, local spin levels are formed, which is an energetically favourable localization of "left" spins (which are opposite to the main direction). Such systems are characterised by elementary excitations of two types, namely, the usual spin waves and "right" spins on the defects. Let us denote by z the maximum number of "left" spins which can be localized on a single defect and let us assume for simplicity that the energy associated with the reversal of one of them ΔE is independent of the number of the remaining spins. Then the average number of "right" spins near the given defect will be (Ter Haar - Ref 2) given by Eq (1). Assume further that the concentration of defects of this type is c , the spontaneous magnetization at a temperature T is given by Eq (2),

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where $f(T)$ is a function which is determined by the average number of spin waves and M_o is a constant. In particular when $z \geqslant 2$ and $T \ll T_c^o$ (T_c is the usual Curie point), Eq (2) assumes the form given by Eq (3). As was pointed out in Ref 1, the concept of local spin levels remains valid even with relatively large concentration of defects. It is therefore possible, in principle, that the condition given by Eq (4) may hold. However, when $T \gtrsim T_o > 0$, the bracket in Eq (3) is positive ($T_o \ll T_c$). This means that at absolute zero, the substance is not ferromagnetic but at some temperature T_o (which is smaller than the Curie point) it transforms into a ferromagnetic due to the spin flip on local levels. The condition $T_o \ll T_c$ ensures that the demagnetization effect of spin waves is small. In this way one obtains a ferromagnetic with two Curie points. T_o is given by Eq (5) and it follows that the condition for the existence

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On Ferromagnetics with Two Curie Points

of such a substance is given by Eq (6) in addition to the inequality $T_o \ll T_c$. The effect of the disappearance of ferromagnetism at low temperatures should be sought in solid solutions of nonferromagnetics and ferromagnetics. There are 3 references, 1 of which is English and 2 Soviet.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet imeni Lomonosova (Moscow State University imeni Lomonosov)

SUBMITTED: November 10, 1958

Card 3/3

5(4) SOV/76-33-7-40/40

AUTHORS: Bonch-Bruyevich, V. L., Sandomirskiy, V. B.

TITLE: Fedor Fedorovich Vol'kenshteyn. On the Occasion of His 50th Birthday

PERIODICAL: Zhurnal fizicheskoy khimii, 1959, Vol 33, Nr 7, p 1676 (USSR)

ABSTRACT: On December 10, 1958 F. F. Vol'kenshteyn, Doctor of Physical and Mathematical Sciences, celebrated his 50th birthday. In 1931 he completed his studies at the Leningradskiy politekhnicheskiy institut (Leningrad Polytechnic Institute), and afterwards he specialized in theoretical investigations of electron processes in condensated media. In this field he obtained, among other things, various important results concerning the theory of dielectrics and semiconductors. These results were published in the books "Proboy zhidkikh dielektrikov" ("Sparkover in Liquid Dielectrics") and "Elektroprovodnost' poluprovodnikov" ("Electrical Conductivity of Semiconductors"). In 1944 he was invited by S. Z. Roginskiy to write articles on chemisorption and catalytic processes. Also in this field he was very successful. The results he obtained by investigating the spectra of

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Fedor Fedorovich Vol'kenshteyn. On the Occasion of His 50th Birthday SOV/76-33-7-40/40

energy levels of the crystal surface with atoms adsorbed hereupon, as well as his publications of the conditions of electron equilibrium between the individual kinds of adsorbed substances and between the surface and the body permitted an investigation of the reactivity of adsorbed substances as well as of the influence exercised by external factors upon adsorption and catalytic processes. These works give an idea of the processes of chemisorption on the surface of semiconductors and may form the basis of a further development of the quantum theory of heterogeneous catalysis. There is 1 figure.

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24(3) SOV/56-36-3-45/71

AUTHOR: Bonch-Bruyevich, V. L.

TITLE: On a Method of Calculating Electric Conductivity (Ob odnom metode vychisleniya elektroprovodnosti)

PERIODICAL: Zhurnal eksperimental'noy i teoreticheskoy fiziki, 1959, Vol 36, Nr 3, pp 924-926 (USSR)

ABSTRACT: It is known that the standard methods of the equation of motion in the electron theory of solids lead to a number of difficulties (cf. Refs 1-3). In this connection already many authors endeavored to develop a rigorous theory of kinetic coefficients by means of the apparatus of relaxation functions (Refs 4-7). In the present "Letter to the Editor" the author suggests a new method of calculating the manner in which a particle system reacts to an external field. For this purpose the author uses Green's (Grin) quantum functions. For the connection between the density matrix and Green's one-fermion function it is assumed to hold that

$R_2(\vec{x},\vec{y};t) = i \lim G(x,y)$ at $x_0 \rightarrow y_0 = t$, $x_0 < y_0$

Under the influence of a field which is characterized by the four-potential A_i, it holds for the variation of G that

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On a Method of Calculating Electric Conductivity

$$\Delta G(x,y) = (e/\hbar)\int dz dz' dz'' G_o(x_1 z')\Gamma_i(z',z'';z)G_o(z'',y)A_i(z)$$

For the spatially-homogeneous case $\hbar = 1$ and finite electric conductivity one obtains

$$\Delta G(x,y)\Big|_{s=o} = eA_i(y)(2\pi)^4\int dpG_o(p)G_o(p-k)\Gamma_i(p,p-k)e^{-i(p,x-y)}$$

For purposes of illustration, the author in the following investigates the case of a constant field, and derives further formulae for the variation of the occupation number Δn_p in the momentum space, the conductivity tensor, and the relaxation time. There are 8 references, 6 of which are Soviet.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet (Moscow State University)

SUBMITTED: September 15, 1958

9(3), 18(0) SOV/20-124-5-15/62

AUTHORS: Bonch-Bruyevich, V. L., Glasko, V. B.

TITLE: On the Energy Spectrum of Electrons in the Non-ideal Lattice of a Metal (Ob energeticheskom spektre elektronov v neideal'noy reshetke metalla)

PERIODICAL: Doklady Akademii nauk SSSR, 1959, Vol 124, Nr 5, pp 1015-1017 (USSR)

ABSTRACT: The influence exercised by the microdefects of structure on the energy spectrum of a metal is of essential importance for some problems of the physics of solids. It especially forms the quantum-mechanical basis of the theory of chemical adsorption on a metal, and it also plays an important part in impurity scattering. Solution of this problem requires considerable dynamic investigation. The authors investigate defects of the type of the hydrogen-like atoms which penetrated into the lattice. (All quantitative results may be applied without difficulty also to more complicated cases). The problem is then reduced to the investigation of the variation of energy and electron-density on the addition of an electron to the system while maintaining the neutrality condition. This problem may be solved comparatively quickly as soon as the

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"one-particle" Fermi-Green function $G(x,y)$ for the given system is known. Here x,y denote four-points and it holds that $x = \{x_0, \vec{x}\}$. The "one-particle" density matrix $R(\vec{x},\vec{y};t)$ for the ground state and the frequencies ω occurring in the spectral decomposition of the function $G(x,y)$ immediately supply the required energy variations. These frequencies are, within the framework of the improved perturbation theory, the eigenvalues of a here given and explained equation. This equation is obtained by successively solving the many-electron problem without the otherwise necessary assumption of smallness of the dimensionless coupling constant. Although this equation agrees formally with certain Schroedinger equations for an electron, it actually describes a many-electron system, and its eigenvalues have by no means the meaning of anything like "One-electron-energies". The most sensible way of dealing with the problem according to the authors opinion consists in calculating the effects connected with the structural effect in the case of a known Fermi spectrum of electrons in a perfect lattice.

On the Energy Spectrum of Electrons in the Non-ideal Lattice of a Metal SOV/20-124-5-15/62

It is possible to subdivide all metals into two classes with respect to the given type of impurities (or other structural microdefects), and the same is the case with all impurities with respect to the given metal, according to whether "local levels" exist or not. In the former case, the impurities which have penetrated are neutral in the ground state, and in the second, they are ionized. This subdivision is, however, by no means absolute, for with a variation of the electron concentration in the metal, the system is able to pass from one class to the other. The here discussed qualitative considerations are convincing only if the critical parameter values of the problem are plausible. For this purpose the above-mentioned equation was numerically solved by means of the "Strela" computer of the Vychislitelnyy tsentr MGU (Computing Center of Moscow State University) under certain conditions mentioned. The critical values of the coupling constant and the first eigenvalues are given in a table. The authors thank F. F. Vol'kenshteyn, S. Z. Roginskiy, and A. N. Tikhonov for discussing this paper. There are 2 tables and 8 references, 7 of which are Soviet.

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On the Energy Spectrum of Electrons in the Non-ideal Lattice of a Metal SOV/20-124-5-15/62

ASSOCIATION: Moskovskiy gosudarstvennyy universitet im. M. V. Lomonosova (Moscow State University imeni M. V. Lomonosov)

PRESENTED: October 31, 1958, by A. F. Ioffe, Academician

SUBMITTED: August 12, 1958

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18(0), 9(3) SOV/20-124-6-14/55

AUTHOR: Bonch-Bruyevich, V. L.

TITLE: On the Relation Between the Constants of the Interaction of Electrons With Phonons and With Impurities in Metals (O svyazi mezhdu konstantami vzaimodeystviya elektronov s fononami i s primesyami v metallakh)

PERIODICAL: Doklady Akademii nauk SSSR, 1959, Vol 124, Nr 6, pp 1233 - 1235 (USSR)

ABSTRACT: In the theory of the electric conductivity of metals the constants characterizing interaction of electrons with lattice oscillations and with the various structural defects (e.g. with the impurity centers) are introduced either by means of the Thomas-Fermi method or by the semi-phenomenological method. These two methods are very closely connected as will be shown by the present paper. First, interaction between electrons and phonons is investigated in conjugation with an additional field which occurs while the ions of the metal lattice are shifted from equilibrium. Screening is rigorously taken into account by the author according to the method of Green's function. In any case, the concept of local interaction is in itself an

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approximated one which can be used only by neglecting the "radiative corrections" to the vertex part. Calculation is followed step by step, and the following result is eventually obtained: The constant C of the interaction between electrons and phonons is immediately connected with the radius of the screening of the static field by free electrons: $C = (3/2)nr_0^2e^2$. Here n denotes ion concentration and r_0 - the radius of screening. The reason for this connection is obvious: Because of the smallness of the phonon frequencies as against the Fermi frequency, the additional field connected with the lattice oscillations practically does not differ at all from a static field with respect to its influence upon the electrons on the metal. There are 7 references, 4 of which are Soviet.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet im. M. V. Lomonosova (Moscow State University imeni M. V. Lomonosov)

PRESENTED: October 31, 1958, by A. F. Ioffe, Academician

SUBMITTED: August 12, 1958

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24 (5)

AUTHOR: Bonch-Bruyevich, V. L. SOV/20-126-3-22/69

TITLE: On the Theory of the Temperature Functions of Green (K teorii temperaturnykh funktsiy Grina)

PERIODICAL: Doklady Akademii nauk SSSR, 1959, Vol 126, Nr 3, pp 539-542 (USSR)

ABSTRACT: In the first part of the present paper a survey is given of the significance of Green's functions for quantum mechanics and especially for the electron theory in solids. Green's function (1) is discussed, and it is shown that the pair of correlation functions may be expressed by it. The density matrix in the momentum space is then dealt with, and in the second part the energy spectrum of a many-body problem is investigated. In this connection, the "effective wave equation", as found in the Dirac equation, is deduced. The propagation function of the momenta in the nondegenerated electron gas is dealt with by the third part. Here, the methods developed in this paper are applied, and formula (12) is found by means of the spectral theorem (Refs 9, 10). By means of the Green's function the polar concentration of the conduction electron is obtained herefrom, which is of great interest for

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germanium semiconductors. In conclusion, the author thanks N. N. Bogolyubov and Sh. M. Kogan for their interest in this work and for discussing the results obtained. There are 11 references, 9 of which are Soviet.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet im. M. V. Lomonosova (Moscow State University imeni M. V. Lomonosov)

PRESENTED: February 16, 1959, by N. N. Bogolyubov, Academician

SUBMITTED: February 11, 1959

APPROVED FOR RELEASE: 06/09/2000 CIA-RDP86-00513R000206210010-9"

24 (5)

AUTHOR: Bonch-Bruyevich, V. L. SOV/20-129-3-15/70

TITLE: The Spectral Representations of the Many-time Temperature Functions of Green

PERIODICAL: Doklady Akademii nauk SSSR, 1959, Vol 129, Nr 3, pp 529-532 (USSR)

ABSTRACT: The causal Green's function is not analytical for $T \neq 0$, which may render its use considerably difficult. These difficulties, however, do not arise, if not the causal but the advanced and the retarded Green's function are investigated. This method is employed in the present paper. The author investigates triple products of the form $K(x,x',x'') = \langle A(x)B(x')C(x'')\rangle$. Here A, B, C denote arbitrary local operators, $x = \{x_0, \lambda\}$; x_0 - time, λ - the totality of arbitrary variables (e.g. the triple of the spatial coordinates and of the spin coordinate). The symbol $\langle ... \rangle$ denotes averaging over a large Gibbs assembly. The author investigates the system under steady conditions and by Φ_n and E_n he denotes the eigenfunctions and eigenvalues of their total Hamiltonian. In this case, the generalized Hamiltonian is concerned, which also contains the term μN, where μ denotes the Gibbs potential of the system and N the

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operator of the total number of particles. $K(x,x',x'') = \sum_{n,m,l} p_n(\Phi_n, A\Phi_m)(\Phi_m, B\Phi_l)(\Phi_l, C\Phi_n)$ obviously holds. Here $p_n = \exp\beta(\Omega - E_n)$; $\beta = 1/kT$ holds, and Ω denotes the thermodynamic potential. If $t = x_0 - x'_0$, $t' = x'_0 - x''_0$ is put, $K(x,x',x'') = \int_{-\infty}^{+\infty} dEdE' \exp\left[-iEt - iE't'\right] I(\lambda,\lambda',\lambda'',E,E')$ is obtained. The problem consists in the investigation of the function I. Together with I, retarded and advanced structures are introduced. The expression for $I(E,E')$ resulting after some steps is explicitly written down. The next paragraph deals with the causal Green's function: $K_c(x,x',x'') = \langle T\{A(x)B(x')C(x'')\}\rangle$. This causal function is expressed by two spectral functions. Next, the integral equation $K_c(x,x',x'')$ and the expression for $K_c(E,E')$ are written down. In quite a similar manner also the mean values of the products of n operators may be investigated. The very voluminous formulas obtained thereby are not written down in the present paper. The author thanks N. N. Bogolyubov for discussing the present paper. There are 6 Soviet references.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet im. M. V. Lomonosova (Moscow State University imeni M. V. Lomonosov)

PRESENTED: June 11, 1959, by N. N. Bogolyubov, Academician

SUBMITTED: June 10, 1959

BONCH-BRUYEVICH, V.L.; GLASKO, V.B.

Theory of chemical adsorption on metals. Probl. kin. i kat. 10:141-154 '60. (MIRA 14:5)

1. Fizicheskiy fakul'tet Moskovskogo gosudarstvennogo universiteta.
(Adsorption)

81359

S/181/60/002/03/15/028
B006/B017

24.7700

AUTHORS: Bonch-Bruyevich, V. L., Gulyayev, Yu. V.

TITLE: On the Theory of Impact Recombination in Semiconductors

PERIODICAL: Fizika tverdogo tela, 1960, Vol. 2, No. 3, pp. 465-473

TEXT: In the introduction, the authors briefly discuss some papers dealing with the influence exercised by the Auger effect on recombination processes in semiconductors. The present paper deals with the problem of impact recombination in semiconductors, taking into account the interaction between free carriers. Furthermore, the authors attempted to estimate the amount of the exchange term on the capture of minority carriers as well as the influence exercised by Coulomb forces on the capture of such carriers by charged centers. First, the impact recombination coefficients in neutral impurity centers are calculated by using the same approximation methods as in Refs. 4 - 6. According to Ref. 8 $\Phi(r) = \frac{Ze}{r}\exp(-qr)\cos qr$ is chosen as interaction potential;

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On the Theory of Impact Recombination in Semiconductors

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$q = \sqrt{2}\left(\frac{\varkappa n m e^2}{\varepsilon \hbar^2}\right)^{1/4}$, n is the concentration of free carriers. An n-type semiconductor is considered, i.e., recombination takes place at neutral centers. At a sufficiently high concentration of majority carriers, the recombination cross section is determined by the capture cross section of the minority carriers (holes). The processes contributing to the matrix element of the transition (from state n into state k) are schematically shown in Figs. 1 and 2. A general and some special expressions were obtained for the recombination coefficient. The capture cross section in n-type germanium at 300°K, $\beta = m/m_0$ (ratio between effective and true carrier mass) - $\beta = 0.2$, trap depth $E_t \simeq 0.3$ ev ($\Delta E = 0.66$ ev) is estimated to be $\sigma_p \simeq 10^{-34} n_0 \mathrm{cm}^2$; $\sigma_p \simeq 10^{-17} \mathrm{cm}^2$ at $n_0 = 10^{17}\ \mathrm{cm}^{-3}$. In the second chapter, the coefficient of impact recombination is again calculated by using another trap model ("trap radius" small compared with the thermal wavelength of the free carriers). In the third chapter, it is assumed that the recombination centers are charged, and the capture mechanism is investigated for this case. It was found that the charge sign of the trap exercises no influence on

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On the Theory of Impact Recombination in Semiconductors

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B006/B017

the impact-recombination mechanism. In a capture of carriers at charged centers, the recombination coefficient is reduced by the action of the Coulomb field (compared with neutral centers). This reduction is, however, within the error limits of the computations. There are 2 figures and 12 references: 6 Soviet, 3 US, 2 British, and 1 Polish.

ASSOCIATION: Institut radiotekhniki i elektroniki AN SSSR Moskva (Institute of Radio Engineering and Electronics of the AS USSR, Moscow)

SUBMITTED: May 23, 1959

Card 3/3

81361
S/181/60/002/03/18/028
B006/B017

24.2120

AUTHORS: Bonch-Bruyevich, V. L., Mironov, A. G.

TITLE: On the Theory of the Electron Plasma 21 in the Magnetic Field 21

PERIODICAL: Fizika tverdogo tela, 1960, Vol. 2, No. 3, pp. 489-498

TEXT: The aim of the present paper was to investigate theoretically the behavior of a non-degenerate electron plasma in a constant magnetic field. Similar investigations by the method of Green functions have repeatedly been made for the case without field. The existence of a magnetic field causes an additional anisotropy of the plasma properties and a number of characteristic resonance effects. The properties of an electron plasma in a magnetic field have also been investigated by using the equation of motion. In this case the authors use Green functions, not in order to deduce known results by a more complicated method, but to develop a mathematical apparatus which can be used for solving more complicated tasks. This development of the technique is the most essential factor; the spectrum of plasma oscillations 21 serves only for verifying the method.

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On the Theory of the Electron Plasma in the Magnetic Field S/181/60/002/03/18/028 B006/B017

It is found, however, that by using Green functions some new results can be obtained, which are connected with the fact that the quantum corrections and the anisotropy of isoenergetic surfaces have been taken into account. They are of importance for investigating the electron-hole plasmas in solid-state physics. A system of a non-degenerate electron plasma of concentration n in volume V is studied (similarly to the system of conduction electrons or holes in a semiconductor). The neutrality of the system is guaranteed by the regular distribution of the positive charge. At a temperature T, the electrons are in thermodynamic equilibrium, the magnetic field H is assumed to be constant and homogeneous. First, the authors confine themselves to the isotropic case where the field of the crystal lattice is taken into account by the scalar effective mass m, and investigate Green functions of non-interacting fields. In the following, they compute the total Green boson functions which makes it necessary to determine the polarization operators of the system. The spectrum of plasma oscillations is investigated, and an expression is deduced for the limit of the oscillation wave number and of the attenuation factor by taking into account the quantum correction. The 4

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screening law for the outer electric field and the influence exercised by the magnetic field on it, are investigated in the last part. Some integrations are given in appendices I - III. There are 8 references: 6 Soviet and 2 US.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet, Fizicheskiy fakul'tet (Moscow State University, Physics Department)

SUBMITTED: June 29, 1959

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LANDSBERG, Ye.G.; BONCH-BRUYEVICH, V.L.

Effect of the physical dimensions of samples on the measurement of photo diffusion length by means of the photomagnetic method. Fiz. tver. tela 2 no.5:848-853 My '60. (MIRA 13:10)
(Semiconductors)

83005

S/181/60/002/008/024/045
B006/B063

24.1200

AUTHOR: Bonch-Bruyevich, V. L.

TITLE: The Dependence of the Phonon Spectrum on the Concentration of Free Carriers

PERIODICAL: Fizika tverdogo tela, 1960, Vol. 2, No. 8, pp. 1857 - 1863

TEXT: The effect of electron-phonon interaction in semiconductors on its energy spectrum has hitherto been studied only with respect to carriers. If their concentration is sufficiently high, the phonon spectrum may also be influenced considerably. In particular, the velocity of sound will be dependent on the electron or hole concentration. The "renormalization" of the velocity of sound for electron-phonon interaction has been studied in connection with problems of superconductivity. Whereas the electron concentration in metals is constant, the carrier concentration in semiconductors varies in a wide range, so that "renormalization" becomes significant, and the assumption of a "bare" velocity of sound is fully justified. A "bare" velocity of sound may be

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The Dependence of the Phonon Spectrum on the Concentration of Free Carriers

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observed if there are practically no carriers present. In the present paper, the author studies the problem of the phonon spectrum in the presence of carriers. The method of Green's temperature quantum functions, which he uses, allows the determination of formulas that are valid for all temperatures and any Fermi degeneration. The author considers a homopolar semiconductor of unipolar (n-type) conductivity, and for the electron-phonon interaction he assumes an isotropic law. After supplying some fundamental relations, he gives the Green phonon functions for spatially homogeneous systems and treats them by perturbation theory. An explicit expression given for the polarization operators of these systems is further transformed. The velocity of sound is obtained as a function of the concentration of free electrons. This permits an experimental determination of the constant of the deformation potential provided the dispersion law of these electrons is known. All calculations were made in weak-coupling approximation. There are 13 references: 10 Soviet, 2 US, and 1 British.

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83005

The Dependence of the Phonon Spectrum on the Concentration of Free Carriers

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B006/B063

ASSOCIATION: Moskovskiy gosudarstvennyy universitet Fizicheskiy fakul'tet Kafedra poluprovodnikov (Moscow State University, Department of Physics, Chair of Semiconductors)

SUBMITTED: January 8, 1960

X

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20425

S/109/60/005/012/023/035
E192/382

9.4320 (1043,1143,1395)

AUTHOR: Bonch-Bruyevich, V.L.

TITLE: Theory of the Tunnel Diode

PERIODICAL: Radiotekhnika i elektronika, 1960, Vol. 5, No. 12, pp. 2033 - 2037

TEXT: The tunnel diode described by Esaki (Ref. 1) has a number of useful engineering applications and it is therefore important to investigate the principal parameters which determine its voltage-current characteristic. In particular, it is important to find the dependence of the characteristics on the alloying conditions of n- and p-junctions. In order to solve this problem it is necessary to consider not an idealised but an actual crystal. The secondary effects which should be included in such analyses are the impurity zones produced by the local levels of the elements of the third and fifth groups in strongly alloyed samples. Secondly, it is necessary to consider the dislocation zones due to the defects of the crystal lattice. Consequently, in a semiconductor diode the boundary of the inherent zones E_c and E_v do not

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Theory of the Tunnel Diode

coincide with the boundaries of a continuous spectrum; in fact, these lie below and above the forbidden region. The carriers moving in the impurity and dislocation zones contribute to the current as well as the electrons and holes of the inherent zones of the crystal. An attempt is made in this work to investigate the effect of these factors on the current-voltage characteristic. The energy spectrum of the system consists of the electron and hole zones and also of the continuous spectra produced by the impurities and dislocations. If it is assumed that $P_i(W)$ is the probability of a tunnel transition of an electron from the i-th zone in the n-region into a zone in the p-region, this probability can be represented by

$$P_i = \sum_J P_{ij}$$

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where P_{ij} are the probabilities of a transition into each of the latter zones. The density of the tunnel current is given by:

$$I(e\Phi) = \sum_i \int dWf(W)P_i(W)\rho_i(W) \equiv \sum_i I_i(e\Phi) \qquad (1)$$

where e is the charge of an electron,
$f(W)$ is the Fermi distribution function of the electron energies and
$\rho_i(W)$ is a function characterising the form of the i-th zone.

The limits of integration of Eq. (1) can be easily determined if it is assumed that the equilibrium condition is $I = 0$ at $e\Phi = 0$. It is assumed that electron and hole gases are fully degenerate. Depending on the alloying conditions it is possible to distinguish two cases

Theory of the Tunnel Diode

a) $\mu - E_i < E_a - \mu$

b) $\mu - E_i > E_a > \mu$.

where μ is the Fermi level,
E_i is the position of the lower zones in the absence of an external field, and
E_a is the upper boundary of the continuous spectrum.

In the first case, the solution of Eqs. (1) is in the form of

$$I_i(e\Phi) = \theta(E_a - E_i - e\Phi)\{\theta(E_a - \mu - e\Phi)\theta(\mu - E_i - e\Phi)\int_{\mu}^{\mu+e\Phi} A_i(W)\,dW +$$

$$+\theta(e\Phi - \mu + E_i)\theta(E_a - \mu - e\Phi)\int_{E_i+e\Phi}^{\mu+e\Phi} A_i(W)\,dW +$$

$$+\theta(e\Phi - E_a + \mu)\theta(e\Phi - \mu + E_i)\int_{E_i+e\Phi}^{E_a} A_i(W)\,dW\}. \quad (4a)$$

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where θ is a step function and

$$A_i(W) = P_i(W)\rho_i(W) .$$

For the second case, the solution of Eq. (1) is in the form of:

$$+\theta(e\Phi - E_a + \mu)\,\theta(\mu - E_i - e\Phi)\int_{\mu}^{E_a} A_i(W)\,dW + \theta(e\Phi - E_a + \mu)\times$$
$$\times\,\theta(e\Phi - \mu + E_i)\int_{E_i + e\Phi}^{E_a} A_i(W)\,dW). \qquad (4b)$$

The tunnel current will be completely absent when:

$$e\Phi_1 = E_a - E_d \qquad (5) .$$

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Theory of the Tunnel Diode

This shows the position of the minimum on the current-voltage characteristic. It is seen that the value of Φ_1 is dependent on the boundaries of the continuous spectrum. The maximum tunnel current for the first case is obtained when the following is fulfilled:

$$A_c(\mu + e\Phi) - A_c(E_c + e\Phi) = 0 \qquad (6)$$

which indicates that the maximum is determined by the relationship between $\rho_c(W)$ and the density of states in the valency zone. For the second case, the maximum is shown to lie in the following region:

$$E_a - \mu \leq e\Phi_2 \leqslant \mu - E_c \qquad (8) .$$

Eq. (6) can easily be solved provided the zones are assumed

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Theory of the Tunnel Diode

to be parabolic; in this case, it is possible to determine the potential Φ_2 corresponding to the maximum current.

Eqs. (5) - (8) determine the position of the maxima and minima of the tunnel current and relate these to the technology of the diode. The equations are also interesting in that they provide a new means of investigating the effect of impurity and dislocation states in a semiconductor.
There are 4 references: 2 Soviet and 2 non-Soviet.

SUBMITTED: June 18, 1960

Card 7/7

BONCH-BRUYEVICH, Viktor Leopol'dovich; TYABLIKOV, S.V.; GUSEV, A.A., red.; BRUDNO, K.F., tekhn. red.

[Method of Green's functions in statistical mechanics] Metod funktsii Grina v statisticheskoi mekhanike. S predisl. N.N.Bogoliubova. Moskva, Gos. izd-vo fiziko-matem. lit-ry, 1961. 312 p. (MIRA 14:10)

(Potential, Theory of) (Mechanics)

BONCH-BRUYEVICH, V.L., [translator]; MAYKOVA, Ye., red.; GOR'KOVA, Z.D., tekhn.red.; RYBKINA, V.P., tekhn.red.

[Problems in the quantum theory of irreversible processes] Voprosy kvantovoi teorii neobratimykh pretsessov, sbornik statei. Moskva, Izd-vo inostr.lit-ry, 1961. 365 p. Articles translated from the English. (MIRA 15:2)

(Irreversible processes)

S/030/61/000/001/013/017
B105/B206

AUTHOR: Bonch-Bruyevich, V. L., Doctor of Physics and Mathematics

TITLE: New studies in the field of the semiconductor theory

PERIODICAL: Vestnik Akademii nauk SSSR, no. 1, 1961, 113-114

TEXT: The fourth All-Union Conference on the Theory of Semiconductors was held in Tbilisi from October 17 to 22, 1960. It was convened by the Komissiya po poluprovodnikam (Commission for Semiconductors) at the Prezidium Akademii nauk SSSR (Presidium of the Academy of Sciences USSR) jointly with the Akademiya nauk Gruzinskoy SSR (Academy of Sciences of the Gruzinskaya SSR) and the Tbilisskiy universitet (Tbilisi University). Addresses in memory of the late A. F. Ioffe were delivered by E. L. Andronikashvili and S. I. Pekar. The conference was attended by more than 250 physicists from 25 towns of the country and about 100 reports were delivered at the meetings and seminaries. Great attention was paid to the theory of the excitons. The definite clarification of the structure of the edge of the self-absorption band in cuprous oxide was pointed out here above all. One of the studies showed the possible

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B105/B206

role of the exciton states in the polymerization process. Linked with the physics of the excitons is the problem of additional light waves in the solid, which are caused by a three-dimensional dispersion of the dielectric constant of the substance. The investigation of electric properties of the substance in strong magnetic fields was described as being the second main trend. During the last years several new methods were proposed for calculating the electric conductivity and other kinetic coefficients directly from the equation of quantum-mechanics. Reports were also delivered on the theory of paramagnetic resonance in semiconductors, as well as the theories of "hot" electrons and semiconductor instruments. Further reports were delivered on the many-electron theory of the solid, the theory of liquid semiconductors, and the chemical bonding in semiconductors. The Conference made recommendations for the further development of the semiconductor theory, as well as some organizational measures. The quickest possible establishment of an institut poluprovodnikov (Institute of Semiconductors) in Tbilisi, a problemnaya laboratoriya po fizike poluprovodnikov (Special Research Laboratory for the Physics of Semiconductors) at the Moskovskiy universitet (Moscow University) and Problemnaya laboratoriya po teorii

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poluprovodnikov (Special Research Laboratory for the Theory of Semiconductors) at the Kiyevskiy universitet (Kiyev University) was described as being necessary. The establishment of an otdel fiziki poluprovodnikov (Department of the Physics of Semiconductors) within the framework of the Akademiya nauk USSR (Academy of Sciences UkrSSR) was found to be appropriate.

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89273

24.7500 (1136,1143,1160)

S/181/61/003/001/005/042
B102/B212

AUTHORS: Bonch-Bruyevich, V. L. and Glasko, V. B.

TITLE: Theory of electron states related to dislocations. I. Linear dislocations

PERIODICAL: Fizika tverdogo tela, v. 3, no. 1, 1961, 36-46

TEXT: While quantum-mechanical investigations of electron spectra of real semiconductors have so far been limited to point effects, experimental results seem to indicate the existence of acceptor-type levels which are related to linear dislocations. This problem has been studied theoretically by Read, but his purely classical considerations showed no satisfactory results. The authors have now made a quantum-mechanical study of the effect of linear dislocations upon the energy spectrum of an electron (hole) system in a semiconductor. Since this problem is very complicated, it is necessary to start with a simplified model. The dislocations in question are defects which are able to trap electrons, or holes but they expand in one direction only. These linear dislocations are characterized by a quasi-continuous energy spectrum. There are one or several one-

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B102/B212

dimensional "dislocation bands", the width of which should be comparable to that of the conduction band; it may be overlapped by intrinsic bands of the crystal. Dislocation bands may be an important factor in the electrical conductivity of semiconductors at sufficiently low temperatures if there are no carriers in the intrinsic bands; a strong anisotropy in the electric conductivity is expected in this case. The dislocation bands of Ge and Si are assumed to have n-type conductivity. However, this can be only affirmed if it is known, to what degree the band is filled. First, the mathematical formulation of the problem is discussed in detail. To set up the wave equation, it is assumed that the bands are simple and the wave functions of trapped holes change smoothly enough with increasing distance from the dislocation. Starting from the well-known wave equation in cylindrical coordinates $\left\{E(-i\hbar\nabla_{r,\varphi}, -i\hbar\frac{\partial}{\partial z}) + V(r,\varphi) - W\right\}\psi = 0$ with the substitution $\psi = e^{ikr}\chi(r,\varphi)$ one obtains: $\left\{-\left[\hbar^2/2m(k)\right]\nabla^2_{r,\varphi} + V(r,\varphi) - \lambda\right\}\chi = 0$ with $W = \lambda + E(0,0,\hbar k)$. Now, a linear dislocation is considered to be a charged line, and the potential behavior near this dislocation is examined. $V(r,\varphi)$ is defined 1) by the screened electrostatic field V_c of the charged dislocation, and 2) by the deformation potential V_d, which are given by $V_0(r) = -(2e/2\pi\varepsilon)K_0(r/L)$ and $V_d \sim \sin\varphi/r$; ε is the dielectric constant; $q\dot{\varphi} > 0$, $L = \sqrt{\frac{\varepsilon kT}{4\pi ne^2}}$ is the Debye radius; and n is the concentration of majority carrier in the "intrinsic" band. Concrete examples (hole spectrum) are used to discuss the problem. The problem is reduced to a determination of the solutions of the corresponding Cauchy problem. The eigenvalues are computed, and the dependence of the integral curves upon the introduced dimensionless quantities $x = r/L$, $\lambda' = -\lambda/E_0$, $g^2 = n_d e^2/2\pi\varepsilon E_0$ ($n_d = q/e$ is the number of electrons per unit length of dislocation; d is the lattice constant; and E_0 is the characteristic energy ($E_0 = \hbar^2/2mL^2$)) is investigated graphically. Some of these quantities have been tabulated for m = 0 and -1; a rough evaluation (for $d = 5\cdot10^{-8}$ cm, $m = 0.2m_0$, $\varepsilon = 16$) yields: $E = 1.12\cdot10^{-20}$ n. $\frac{300}{T^oK}$ ev, $g^2 = 2.56f\cdot10^{18}\ n^{-1}\ \frac{T^oK}{300}$, and $L = 4.8\cdot10^2\ n^{-1/2}(T^oK/300)^{1/2}$. Therefore, the edge of the dislocation

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band is a function of temperature. The authors thank S. G. Kalashnikov and A. N. Tikhonov for discussions, and the laboratory assistant L. F. Suzdal'tseva for helping in numerical computations. There are 4 figures, 4 tables, and 10 references 5 Soviet-bloc and 5 non-Soviet-bloc.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet Fizicheskiy fakul'tet (Moscow State University, Division of Physics) Kafedra poluprovodnikov i kafedra matematiki (Department of Semiconductors and Department of Mathematics)

SUBMITTED: May 16, 1960

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S/181/61/003/001/006/042
B102/B212

Theory of electron states related...

For a pure displacement and div $\vec{u} = 0$, the potential (V') is a function of curl $\vec{u}$. Introducing cylindrical coordinates yields the following relation for screw dislocations if div $\vec{u} = 0$: $V' = \alpha/r$; α is a phenomenological constant. The equation of motion for the carriers has the same form as that in I, with the exception that the screened Coulomb potential of the charged line has been replaced by V'. This is valid: $\{E(-i\hbar\nabla)+V'/r-W\}\psi = 0$; and as in I:

$$\psi = e^{ipz}\chi(r, \varphi), \tag{9}$$

$$\left\{-\frac{\hbar^2}{2m(p)}\nabla^2_{r,\varphi} + \frac{V'}{r}\right\}\chi = \lambda\chi, \tag{10}$$

$$\lambda = W - E(0, 0, p), \tag{11}$$

$$\frac{1}{m(p)} = \frac{\partial^2 E(\mathbf{p})}{\partial p_x^2} = \frac{\partial^2 E(\mathbf{p})}{\partial p_y^2}\,(p_x = p_y = 0,\ p_z = p) \tag{12}$$

the author restricts himself to the range $m(p) > 0$ (p - quasi-momentum). λ in the continuous spectrum of the dislocation band (10) is expressed by $\chi(r,\varphi) = e^{il\varphi}r^{|l|}\exp(-2r/a(1+2n+2|l|))F(-n,2|l|+1,4r/a(1+2n+2|l|))$; F denotes a degenerate hypergeometric function, and $a = \hbar/\sqrt{2/mW_0}$. Spectrum

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(10) corresponds to carriers moving in the "intrinsic" bands of the crystal (conduction electrons of holes); the carriers are scattered from the field of the deformation potential of the dislocations. Scattering is investigated for the case of a two-dimensional cylindrically symmetric field. The solution wanted has the form:

$$\chi = e^{ik(u-v)/2}\,\frac{\Gamma\left(\frac{1}{2}+\frac{i}{ak}\right)}{\Gamma\left(\frac{1}{2}\right)}\,e^{-\pi/2ak}F(-i/ak,1/2,ikv); \qquad u = r(1+\cos\varphi) \quad v = r(1-\cos\varphi);$$

F is again a degenerate hypergeometric function. The author has obtained the following expressions for the effective scattering mean free path and the reciprocal value of the relaxation time:

$$L(\varphi) = \frac{\Gamma\left(\frac{1}{2}+\frac{i}{ak}\right)}{\Gamma\left(-\frac{i}{ak}\right)}\,e^{-\frac{\pi i}{4}}\,\frac{\sqrt{a}}{\sqrt{k(1-\cos\varphi)}}, \tag{22}$$

$$\frac{1}{\tau} = \frac{1}{\tau_0}\sqrt{\frac{W_0}{W-E(0,0,p)}}\,\mathrm{th}\left(\frac{\pi}{2}\sqrt{\frac{W_0}{W-E(0,0,p)}}\right), \tag{23}$$

$$\tau_0 = \frac{2m}{\pi\hbar N_d}, \tag{24}$$

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$W_0 = 2m\alpha^2/\hbar^2$ stands for the characteristic energy. The author thanks S. G. Kalashnikov for discussions; A. A. Tuzhilin is mentioned. There are 5 references: 3 Soviet-bloc and 2 non-Soviet-bloc.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet, fizicheskiy fakul'tet (Moscow State University, Division of Physics)

SUBMITTED: May 16, 1960

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20787
S/181/61/003/003/012/030
B102/B205

9.4300 (1136,1143,1150)

AUTHOR: Bonch-Bruyevich, V. L.

TITLE: Some peculiarities of the energy spectrum of many-electron systems in a semiconductor

PERIODICAL: Fizika tverdogo tela, v. 3, no. 3, 1961, 768-775

TEXT: A theoretical study has been made of the effect of fluctuations in the concentration of free carriers upon the electron spectrum in perfect and imperfect semiconductors. Some peculiarities of many-electron systems, which are related to collective effects, are described with the aid of results presented in several previous publications of the present author. The first part deals with the fluctuation of the parameters of the electron spectrum. In principle, these fluctuations can be ascribed to temperature and density variations. Whereas the former are insignificant under normal conditions, the latter may have a great influence. The density variations can be subdivided into two types, namely, a type in which the total number of carriers in a certain band varies, and a type in which it does not vary. Thus, two decay times are to be distinguished: in the first case, the mean free time

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Some peculiarities ...

τ, and in the second case, the recombination time τ_r. A sufficient condition for the neglect of variations in the first case is given by $\tau \ll \hbar/E$, where E is the characteristic energy of the problem, obtained by the solution of the wave equation. This condition is considered to be satisfied. In the second case, the following condition is valid: $\tau_r \gg \hbar/E$. It is further assumed that the effective wave functions of the unperturbed system are formally known. Thus, the problem can be reduced to a determination of the additional term due to fluctuations. This additional term to the Hamiltonian is formulated as $\Delta H(\vec{x}) \simeq \int d\vec{y} V(\vec{x},\vec{y}) \Delta n(\vec{y},t)$, where $\Delta n(\vec{y},t)$ is a random deviation of the free carrier concentration at the point $\vec{y}$, at the instant t from the equilibrium value $\bar{n}(\vec{y})$. Calculation of the fluctuations in the spectrum leads to a calculation of the shift of the eigenvalues of the effective wave equation on a change of the carrier concentration. In first approximation, one obtains $\Delta E_1 \simeq \int d\vec{y} F_1(\vec{y}) \Delta n(\vec{y},t)$ with $F_1(\vec{y}) = \int d\vec{x} |\chi_1(\vec{x})|^2 V(\vec{x},\vec{y})$ (5), and in second perturbation-theoretical approximation, one has

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$$\overline{\Delta E^{(2)}} = \sum_{l' \neq l} \frac{F_{ll'}}{E_l - E_{l'}},$$

(8), (9) $$F_{ll'} = \int d\mathbf{x} d\mathbf{x}' \bar{\chi}_{l'}(\mathbf{x}) \chi_l(\mathbf{x}) \bar{\chi}_l(\mathbf{x}') \chi_{l'}(\mathbf{x}') \times$$
$$\times \left\{ \int d\mathbf{y}\, \bar{n}(\mathbf{y}) V(\mathbf{x}, \mathbf{y}) \left[V(\mathbf{x}', \mathbf{y}) + \int d\mathbf{y}' V(\mathbf{x}', \mathbf{y}') \nu(\mathbf{y}, \mathbf{y}') \right] \right\}.$$

Formula (5) and

$$\overline{\Delta E_l} = 0, \quad \overline{\Delta E_l^2} = \int d\mathbf{y} F^2(\mathbf{y}) \bar{n}(\mathbf{y}) + \int d\mathbf{y} d\mathbf{y}' F(\mathbf{y}) F(\mathbf{y}') \nu(\mathbf{y}, \mathbf{y}') \bar{n}(\mathbf{y}). \quad (7)$$

are used to estimate the fluctuations in the effective carrier mass and in the ionization (or excitation) energy of an impurity center with shallow levels. In the former case, one restricts oneself to ideal crystals and obtains: $\frac{\overline{\Delta E^2}}{I_o^2} \simeq \frac{6\pi n a_o^2}{\alpha}$, where $a_o = \varepsilon\hbar^2/me^2$, $I_o = e^2/\varepsilon a_o$, $\alpha^4 = 4\pi nme^2/\varepsilon\hbar^2$. For $n = 10^{17}\,cm^{-3}$, $m = 0.2\,m_o$, $\varepsilon = 16$ one has $\overline{\Delta E^2}/I_o^2 \simeq 0.2$. In the second part, the author discusses the vanishing of levels. This means that at a sufficiently

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high carrier concentration ($n>n_{crit}$), impurity centers or defects show no local states or, in other words, those existing at $n<n_{crit}$ vanish. This effect is related to a change in the screening potential. The effects of several factors on the critical concentration n_{crit} are briefly discussed. In this connection, the author thanks P. G. Yeliseyev for a valuable hint. There are 10 references: 9 Soviet-bloc and 1 non-Soviet-bloc. The reference to the English-language publication reads as follows: M. Lax, Rev. Med. Phys. 32, 25, 1960.

ASSOCIATION: Moskovskiy gosudarstvennyy universitet, Fizicheskiy fakul'tet Kafedra poluprovodnikov (Moscow State University, Division of Physics, Department of Semiconductors)

SUBMITTED: July 5, 1960

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29690
S/181/61/003/010/014/036
B111/B138

24,7700(1144,1385,1559)

AUTHORS: Bonch-Bruyevich, V. L., and Mironov, A. G.

TITLE: Effect of impurities on the carrier energy spectrum

PERIODICAL: Fizika tverdogo tela, v. 3, no. 10, 1961, 3009 - 3021

TEXT: Impurities not only cause a change in carrier parameters (effective mass, momentum distribution function) in a semiconductor, but also a change in the dispersion equation. The authors examine the behavior of carriers in the presence of an impurity. The problem, which is regarded as three-dimensional, is treated with Green's two-time temperature functions. The Hamiltonian is set up as the sum of the kinetic and potential energy operators: $\mathcal{H} = \sum_i (T_i + V_i)$. For semiconductors of unipolar conductivity (n-type) $V_i = \sum_j V(\vec{x}_i - \vec{R}_j)$ is valid, where $\vec{x}_i$ denotes the position vector of the 2nd electron, and $\vec{R}_j$ is the position vector of the j-th impurity center. The perturbation theory may be used to calculate the carrier energy spectrum if the impurity concentration of

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$n \approx 10^{17} - 10^{18}$ cm^{-3} (for Ge). The following holds for the mass operator in coordinate representation:
$M(x,y) = -\langle V'(x)V'(y)\rangle\langle G(x,y)\rangle \equiv -\Phi(x,y)G(x,y)$, where $\langle G(x,y)\rangle$ is the total Green function, averaged over all impurity configurations, $V = \langle V\rangle + V'$, $x = \{\vec{x}, x_o\}$, $y = \{\vec{y}, y_o\}$, $x_o - y_o = t$. A Fourier transformation is performed to calculate $\Phi(x,y)$. $\Phi(\vec{k}, k_o) = \delta(k_o)\varphi(\vec{k})$; $\varphi(\vec{k}) = n|V'(\vec{k})|^2$. The following relation is satisfied:
$M(\vec{k}, k_o) = -\left(\frac{h^2}{2\pi m}\right)^2 n\int d\vec{k}'\sigma(\vec{k}')G(\vec{k}-\vec{k}'; k_o)$ (17), where $\sigma(\vec{k})$ denotes the scattering cross section of an electron scattered elastically by an impurity center, $h\vec{k}$ being transferred in the process. The dispersion equation for $M(\vec{k},\omega)$ reads: $\mathrm{Re}M(\vec{k},\omega) = \frac{1}{\pi}\int_{-\infty}^{+\infty} dE\,\frac{\mathrm{Im}M(\vec{k},E)}{E-\omega}$. $M(\vec{k},\omega)$ is analytic everywhere in the complex plane of k_o, except on the real axis. The carrier spectrum is described by the function

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$I(\vec{k},k_0) = 2\left[1 + e^{\beta(hk_0 - \mu)}\right]^{-1} \cdot \mathrm{Im}G(\vec{k},k_0)$ (20), where $\beta = 1/(\varkappa T)$, μ is the Fermi level, $k_0 = \omega' - i\omega''$. The dispersion equation is obtained by putting the denominator of Im $G(\vec{k},k_0)$ equal to zero, and the solution in the case of a slight attenuation ($\omega'' \ll |\omega'|$) reads:

$$h\omega' - W_{\mathbf{k}} - nV_0 - \mathrm{Re}\, M(\mathbf{k}, \omega') = 0, \tag{23}$$

$$h\omega'' = \frac{\lim\limits_{\omega'' \to +0} \mathrm{Im}\, M(\mathbf{k}, \omega' - i\omega'')}{1 - \frac{\partial\, \mathrm{Re}\, M(\mathbf{k}, \omega')}{\partial h\omega'}}. \tag{24}$$

(23) gives the corrections to the spectrum for interaction between the carriers and impurity centers. (24) gives the attenuation of a "single-particle" state with momentum $h\vec{k}$. The mass operator may be calculated from (17) and (20). For the case of thermal energies, and disregarding attenuation, one may write $\Delta W_k \simeq \mathrm{const}/k^2$, where W_k denotes the

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unperturbed electron energy, calculated from the bottom of the conduction band. As can be seen, the result is a change in the dispersion equation. To give an accurate indication of the corrections to the energy spectrum $\omega'(\vec{k})$ the screened potential V' was determined in Debye approximation. Thus, $\Delta W_k \simeq - W_B n T_0 / 2\pi k^2$, where $W_B = \frac{me^4}{2\varepsilon^2\hbar^2}$.

If $T \to 0$, the electron distribution function will be:

$$n_e = \int_{-\infty}^{+\infty} \frac{\rho(E)dE}{e^{\beta(E-\mu)}+1}$$, where $\rho(E) = \frac{2}{\pi}\int d\vec{k}\,\mathrm{Im}G(\vec{k},E)$ is the "state density". If there is attenuation, an essential requirement is that the energy range, where $\rho(E) \neq 0$, shall not coincide with the spectrum $\hbar\omega'(\vec{k})$. The following relations hold for the effective occupation number N_c in the conduction band in the nondegenerate case, for thermal energies and for $n_e = n$:

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$$N_c = 2\left(\frac{2\pi m^* \varkappa T}{h^2}\right)^{3/2}, \qquad (64)$$

$$m^* = m\left\{1 + 0.027\frac{\hbar\omega_0\lambda_T}{\varkappa T a_B} - 0.0094\frac{(\hbar\omega_0)^2\lambda_T}{(\varkappa T)^2 a_B} + 0.075\left(\frac{\lambda_T\hbar\omega_0}{a_B\varkappa T}\right)^{1/2} + 0.025\left(\frac{\lambda_T^{1/2}\hbar\omega_0}{a_B^{1/2}\varkappa T}\right)^{3/2}\right\}. \qquad (65)$$

$a_B = \frac{\varepsilon\hbar^2}{me^2}$, $\lambda_T = \frac{h}{\sqrt{m\varkappa T}}$, $\omega_0 = \left(\frac{4\pi ne^2}{\varepsilon m}\right)^{1/2}$. There are 9 references: 2 Soviet and 7 non-Soviet. The three most recent references to English-language publications read as follows: V. L. Bonch-Bruyevich, Sh. M. Kogan, Ann. of Phys., 9, 125, 1960. - W. Kohn, J. M. Luttinger, Phys. Rev., 108, 590, 1957. - Edwards, Phil. Mag., 33, 1020, 1958.

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